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Attorney Docket No. DYOUP0211US

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re PATENT application of:

Applicant(s):	David John Richardson et al.
Serial No:	09/802,745
Filed:	March 8, 2001
Title:	OPTICAL TRANSMISSION SYSTEM AND METHOD

SUBMISSION OF PRIORITY DOCUMENT(S)

Assistant Commissioner for Patents
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Dear Sir:

Regarding applicant's claim to convention priority, enclosed herewith is/are certified copy/copies of the following priority application(s):

UK 0005615.0 filed 9 March 2000

Please acknowledge receipt of the enclosed priority document(s).

Respectfully submitted,

RENNER, OTTO, BOISSELLE & SKLAR LLP

By ____________________
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Patents Form 1/77

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2. Patent application number *(The Patent Office will fill in this part)* — **0005615.0** — 9 MAR 2000

3. Full name, address and postcode of the or of each applicant *(underline all surnames)* — UNIVERSITY OF SOUTHAMPTON HIGHFIELD SOUTHAMPTON SO17 1BJ.

   Patents ADP number *(if you know it)* — 7984700001

   If the applicant is a corporate body, give the country/state of its incorporation — UNITED KINGDOM

4. Title of the invention — AN OPTICAL PROCESSING DEVICE BASED ON FIBER GRATING.

5. Name of your agent *(if you have one)*

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)* — ~~INNOVATION AND RESEARCH SUPPOR UNIVERSITY OF SOUTHAMPTON HIGHFIELD SOUTHAMPTON SO17 1BJ~~

   D. YOUNG + CO.
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6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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   a) any applicant named in part 3 is not an inventor, or
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Request for substantive examination (*Patents Form 10/77*)	–
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11. I/We request the grant of a patent on the basis of this applicatio

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An Optical Processing Device based on fiber grating

A 10 Gbit/s, 160 Gchip/s OCDMA coding:decoding system based on superstructured fiber gratings

Abstract

We report the operation of a 10 Gbit/s, 160 Gchip/s OCDMA unipolar:bipolar coding:decoding system based on superstructured fiber gratings. Error free operation over a transmission distance of 25km of standard fiber is demonstrated with no power penalty.

limited pulse conversion, soliton to super-Gaussian pulses, soliton to dispersion managed solitons, Gaussian pulses to square pulses.

14. Extend the grating bandwidths of code-decode grating to up to 200nm or further
15. Extend technique to other wavelength regimes in the range 700nm to 2000nm or further
16. Extend the superstructure decoding technique to correlate (provide matched filtering) directly with the output form a modulated optical source. For example the source can be a directly modulated gain-switched diode, and externally modulated DFB laser, a mode-locked fibre ring laser with external modulation
17. Addition of wavelength division multiplexers and demultiplexers such as arrayed waveguide gratings to facilitate multi-wavelength operation, with one or more wavelengths being operated under the code-division multiplexing technique described previously.
18. Operation of the system with synchronous transmitters and receivers
19. Operation of the system with asynchronous transmitters and receivers
20. Operation of the system with a combination of synchronous and asynchronous transmitters and receivers

This invention can either be viewed as a grating for use in CDM system architectures, a method of using gratings in CDM system architectures, a CDM architecture for optical communications, or a combined CDM and WDM system architecture for optical communications.

By CDM we mean code-division multiplexing systems but also mean ultrafast packet-switched, or other OTDM networks or transmissions systems.

The apparatus can also include one or more of the following features:

1. Incorporation of both dispersion-compensating and encoding or decoding gratings into a single superstructure grating
2. Addition of multiple codes within a single grating – for example two codes at different central wavelengths
3. Further extension of either the grating length or reduction in chip size to increase the code length to codes of greater than 5000 chips, or more, allowing rapid increases in simultaneous users
4. More complex superstructure profiles including amplitude and phase features to shape controllably the individual chip shapes
5. Incorporation of simultaneous additional, multiple functionality within a single grating (decoding/coding) strutures eg loss compensation and dispersion compensation (2^{nd} and 3^{rd} order)
6. The apparatus may be reconfigured such that the superstructure grating as above is used in transmission mode rather than reflective mode
7. To use higher reflectivity versions of the decoder/coder gratings designed using more advanced design algorithms (eg inverse scattering techniques) other than by the Fourier approach
8. To use cascades of one or more code/decode gratings
9. Use advanced codes such as those developed by the mobile-communications community for optimized correlation function definition eg M-sequences, Gold sequences or Kasami codes
10. Use a combination of a decoder grating and nonlinear element such as a semiconductor optical amplifier or fibre-based nonlinear switch to enhance the correlation signal contrast and effect further enhanced processing functions such as optical routing, header removal and rewrite, data packet loading. (eg. FL A
11. Use parallel arrays of coder-decoder gratings to enhance multi-user operation
12. Use of coder/decoder approach to allow reduction of nonlinear optical effects by extending the bit duration in the time domain, thereby reducing optical intensities
13. Use superstructured gratings to shape optical pulses (that may be of a non-optimal form) for a given transmission technique or optical processing function to a more-desirable functional form for onward transmission or processing, eg chirped pulse to transform

Conclusions

- Superstructure FBG technology enables high coding/decoding performance
- Flexibility in code design and device fabrication - code profile is determined by appropriate UV exposure, not phase mask
- Direct comparison of unipolar vs. bipolar operation
- Error-free 10Gbit/s pulse coding/decoding over 25km of SMF with 160Gchip/s code
- 255-chip or longer codes possible using cm-long FBG's and shorter chip durations
- Applications: OCDMA, header recognition in packet-switched networks, etc.

Objectives of this work

- Extend technique to higher data and chip rates
  - 10Gbit/s vs. 125Mbit/s
  - 160Gchip/s vs. 4Gchip/s
- Compare unipolar with bipolar coding
- Increase FBG reflectivity
- BER tests
- Code transmission over 25km of standard fibre link with FBG-based dispersion compensation
- Demonstrate precision and flexibility of FBG writing process

networks. For example our results demonstrate the possibility of using FBGs for header recognition in 160 Gbit/s OTDM based networks.

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[9] M. Ibsen et al: IEEE Phot. Tech. Lett. 10, 842 (1998)

Fig.1 Experimental set-up.

Fig.2 (a) Unipolar grating reflectivity spectrum (theoretical and experimental). The refractive index superstructure is shown inset. The peak reflectivity of this grating was ~3%.
(b) Bipolar grating reflectivity spectrum (theoretical and experimental). The refractive index superstructure is shown inset. The peak reflectivity of this grating was ~50%.

Fig.3 [illegible] Theoretical and experimental pulse intensity autocorrelation functions for the code:decode process for both the unipolar and bipolar grating pairs. 4 Theoretical and experimental pulse intensity autocorrelation functions for the code:decode process both before and after transmission through 25km of (dispersion compensated) standard fiber.

5 (a and b)
Fig.4 BER curves for back to back, and code:decode before and after transmission. Corresponding eye diagrams are shown inset.

We fabricated a matched pair of both unipolar and bipolar seven-chip M-sequence, coding/decoding gratings. The unipolar gratings were similar in design to those used in our earlier experiments [7], only physically much shorter in length. The total grating length in each instance was 4.64mm (corresponding to a temporal code length of 44.8ps) and the individual chip width was 0.66mm (corresponding to a chip length of 6.4ps). Note that grating phase control can be maintained over lengths of order 10cm allowing for considerably longer code sequences than demonstrated herein. The amplitude-modulated superstructure profile used to write the unipolar code grating is shown inset in Fig.2a along with the corresponding theoretical and experimental power reflectivity profiles. The bipolar grating design is shown inset in Fig.2b, and is a pure phase-encoded structure with discrete π phase shifts at the (NRZ) chip transition boundaries. The experimental and theoretical plots are shown in Fig.2b. The agreement between the theoretical and experimental spectral responses of both FBG types is seen to be excellent, highlighting the precision of our grating writing process. Note that **all** of the gratings used in these experiments (including the dispersion compensating FBG) were written by appropriate UV exposure through the same, uniform period phase mask. The decode gratings in both instances are essentially identical to the encoder gratings other than that they have a spatially-reversed refractive index superstructure.

Since our gratings are still relatively weak we are in the Fourier theory grating design limit, such that the impulse response of the grating in the time domain is essentially given by the superstructure modulation profile used to write the grating. We examined the intensity autocorrelation functions of the incident 2ps pulses on reflection from the individual coding/decoding gratings, and found the profiles to be in excellent agreement with our theoretical predictions. In Fig.3 we plot the experimental and theoretical intensity autocorrelations functions of the decoder response to the incident code patterns for both the unipolar and polar cases respectively. The agreement is seen to be excellent in both cases. The system benefits of using the bipolar gratings due to the interferometric background cancellation are self-evident. In Fig.4 we plot the decoder response to the code after it has propagated over the 25km dispersion-compensated transmission line, there is evidence of some correlation signal degradation, however the effects are slight, and in fact negligible in terms of overall system performance.

We performed BER measurements on the coding:decoding process for the bipolar grating, both with and without the 25km transmission. The results are summarised in Fig.5 where it is seen that no power penalty associated with code-decode process is observed in either instance. Eye diagrams for both the simple code:decode and transmitted code:decode case are shown inset within Fig.5. As expected no evidence of temporal features away from the main, chip-length long, correlation peak is observed.

A 10 Gbit/s, 160 Gchip/s OCDMA coding:decoding system based on superstructured fiber gratings

The area of Optical Code Division Multiple Access (OCDMA) systems has received steadily growing interest in recent years [1-8]. OCDMA offers a number of attractive features for future local area networks including higher connectivity, asynchronous multiple-access and more flexible bandwidth management. Much of the increased activity in this area has resulted from improvements in Fiber Bragg Grating (FBG) fabrication technology driven mainly by the stringent requirements of DWDM. It is now possible to design and reliably fabricate superstructured FBGs with truly complex amplitude and phase responses [9], opening up the possibility of using FBG components to perform fundamental OCDMA functions such as the coding and decoding of chip patterns described herein. Superstructured gratings offer advantages in terms of compactness, scalability, integrability, cost and ease of manufacture relative to competing technological approaches. These alternative approaches include the use of arrayed waveguide gratings [2], fiber delay line arrays [3], arrays of discrete FBGs [4], and bulk-grating based systems incorporating some form of spatial light modulator [5].

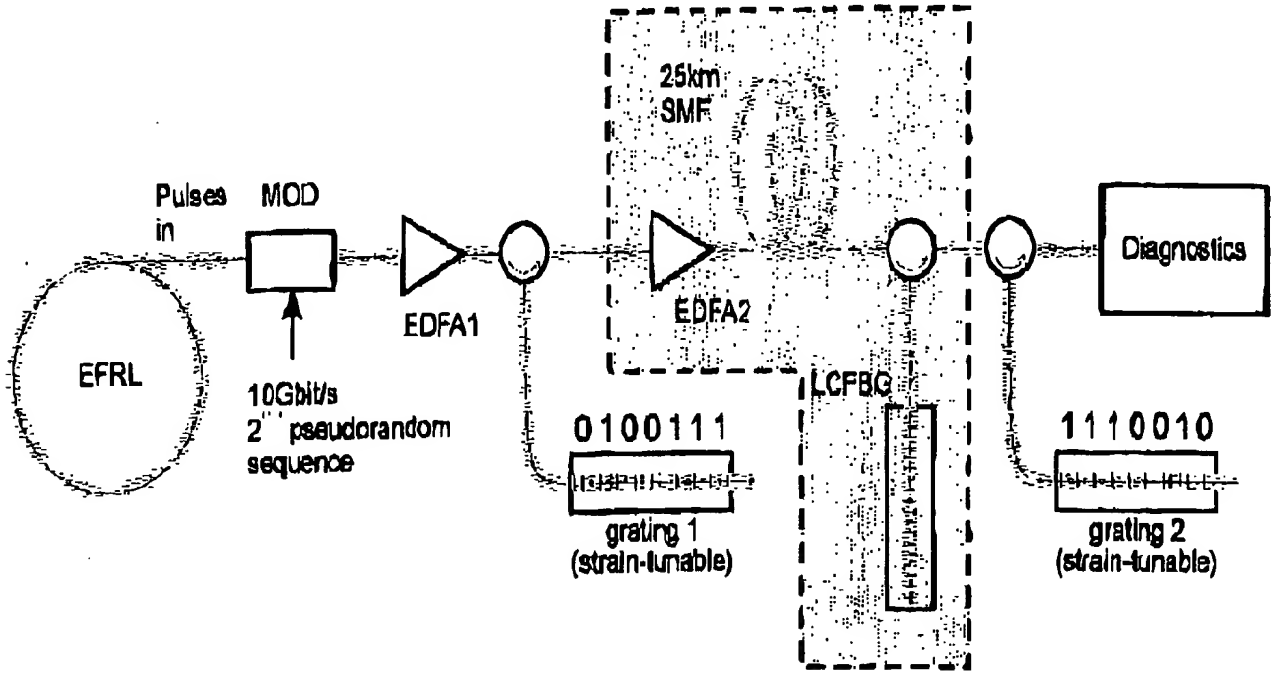
In earlier work we demonstrated the generation of seven-chip, direct sequence, unipolar code OCDMA bits at 125 MHz using a superstructured FBG, and demonstrated optical pattern recognition using a matched FBG filter as a decoder [7]. The general approach has been extended more recently by other authors to bipolar (phase) encoding, resulting in improved code correlation signatures [8]. The repetition rate in these more recent experiments was 20MHz with a chip duration of ~30ps. The FBGs used were of a segmented composite form written through a specially patterned phase mask and had a reflectivity of just 1%.

In this paper we present results on upgrading the superstructure grating approach to both far higher data rates (10 Gbit/s), far shorter chip-lengths (6.4ps) and far higher grating reflectivities (up to 50%) than previously demonstrated. We demonstrate the flexibility and precision of our continuous scanning fiber/phase mask technique by fabricating both unipolar and bipolar coding and decoding gratings with close to the theoretically designed spectral response, and time domain performance characteristics. We present the results of BER measurements at 10 Gbit/s on a decoded pulse sequence both before and after transmission through 25km of standard fiber which show there to be no noise-penalty associated with either the coding:decoding process, or the transmission of the coded pulse itself.

Our experimental set-up is shown in Fig.1 and comprises a 10 Gbit/s, ~2ps pulse transmitter (based on a regeneratively mode-locked, soliton fiber ring laser operating at 10 GHz), coding and decoding gratings, and an (optional) 25km standard fiber transmission span which had its dispersion compensated with a chirped FBG.

FIGURE 1

Experimental set-up

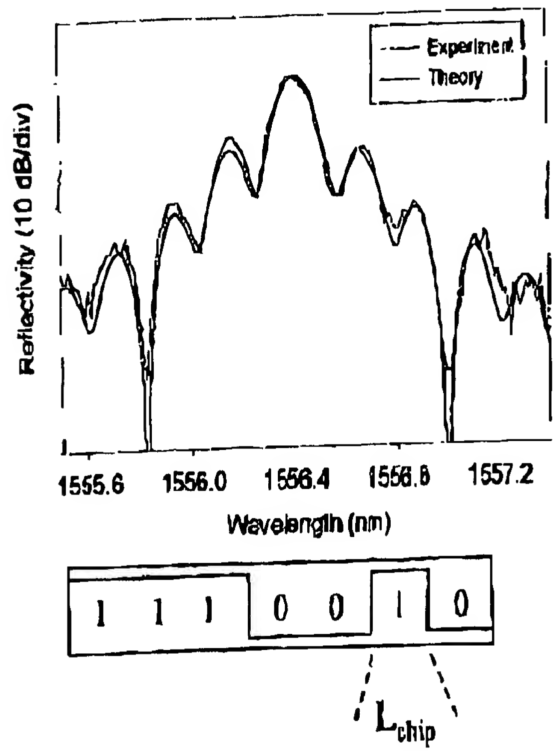


- **Source: Actively, harmonically mode-locked erbium fibre ring laser (2ps soliton pulses at 10GHz)**
- **Transmission over 25km of standard SMF**

Coding/Decoding gratings

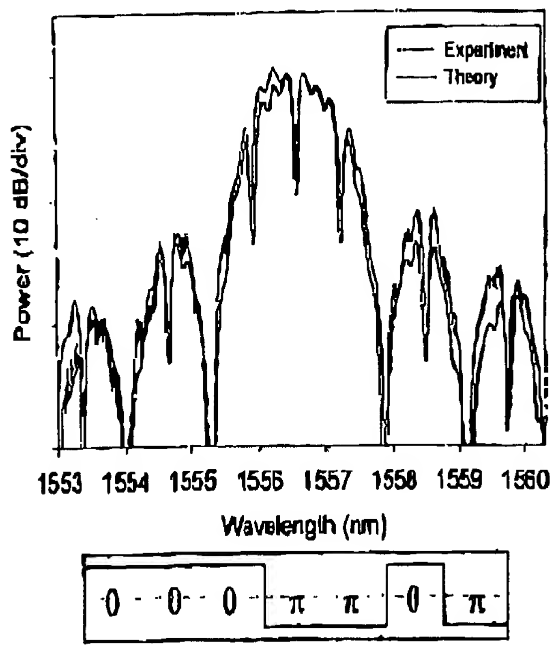
(a) **Unipolar code**

~3% reflective



(b) **Bipolar code**

~50% reflective



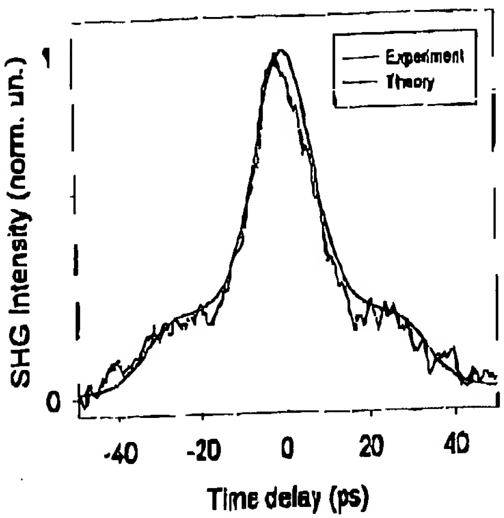
- **Chip duration $\tau_{chip} = 2 \cdot n \cdot L_{chip}/c = 6.4ps$**
- **Duration of codes = 44.8ps**
- **Total grating length = 4.64mm, chip length L_{chip} = 0.66mm**

All FBG's fabricated using a single uniform-pitch phase mask

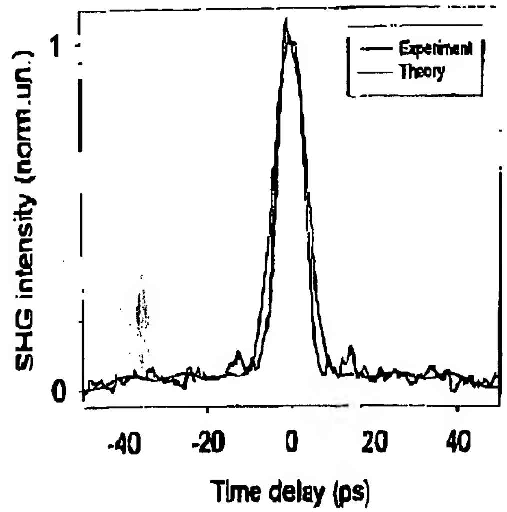
Intensity autocorrelation of decoded signals

FIGURE 3

Unipolar code



Bipolar code



- Good agreement between predicted and experimental waveforms
- Duration of decoded signal = 2 × duration of code = 98.6ps
- Bipolar coding: better background suppression; hence, better signal definition

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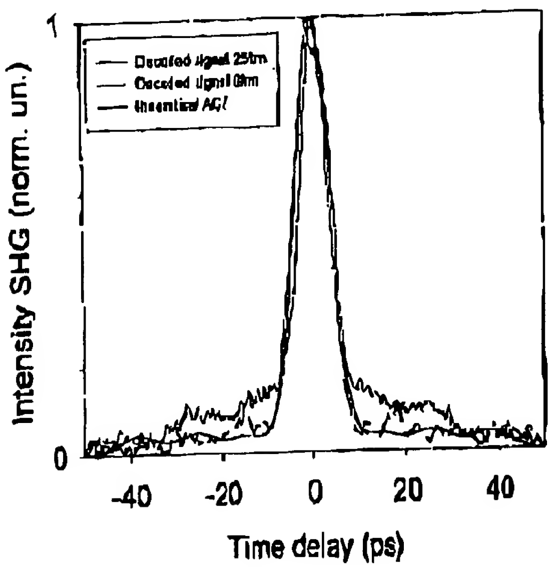
FIGURE 7

Transmission of code over 25km



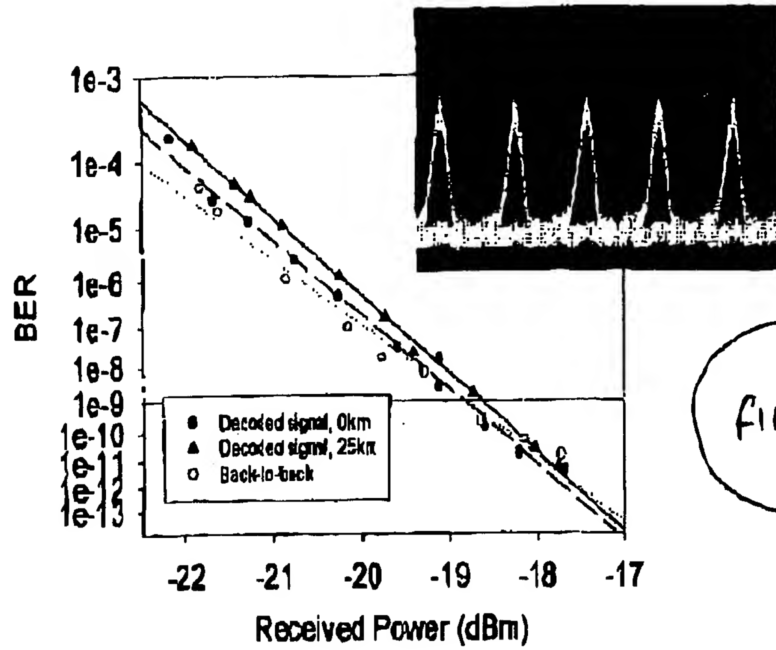


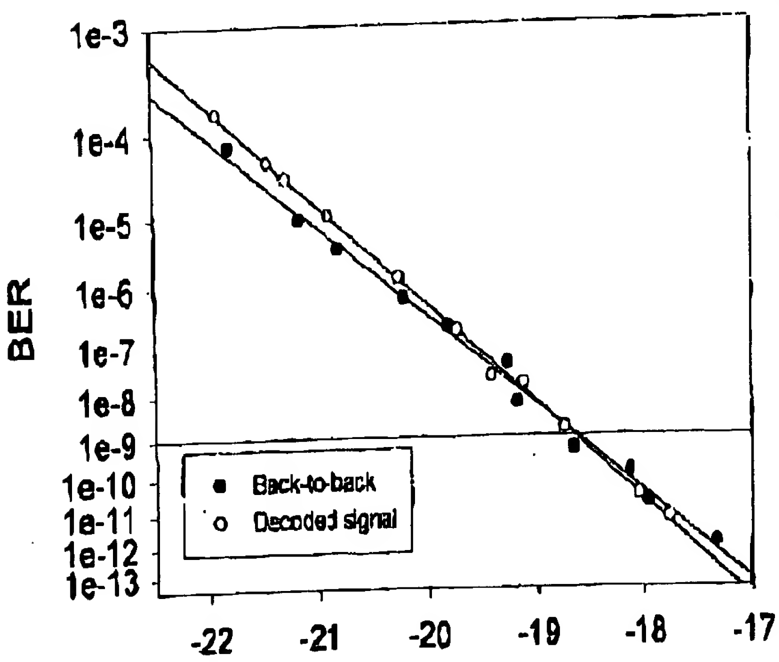
FIGURE 5a

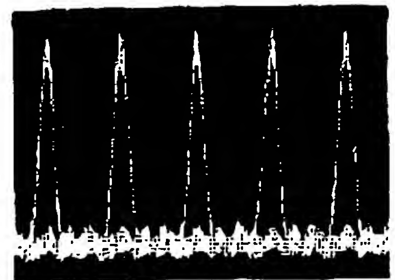
- 25km of standard single-mode fibre
- Dispersion compensation using linearly chirped FBG

Received 09-Mar-00 17:17 From-01703593585 To-THE PATENT OFFICE Page 12

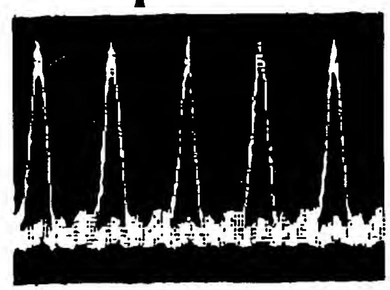
FIGURE 5b

Bipolar coding - BER test





Laser pulses



Decoded signal

- 2^{31}-1 pseudorandom bit sequence
- No noise penalty
- Error-free operation; no noise floor at 10Gbit/s

... SCHEMES BASED ON

CODING / DECODING GRATINGS AND A NONLINEAR ELEMENT

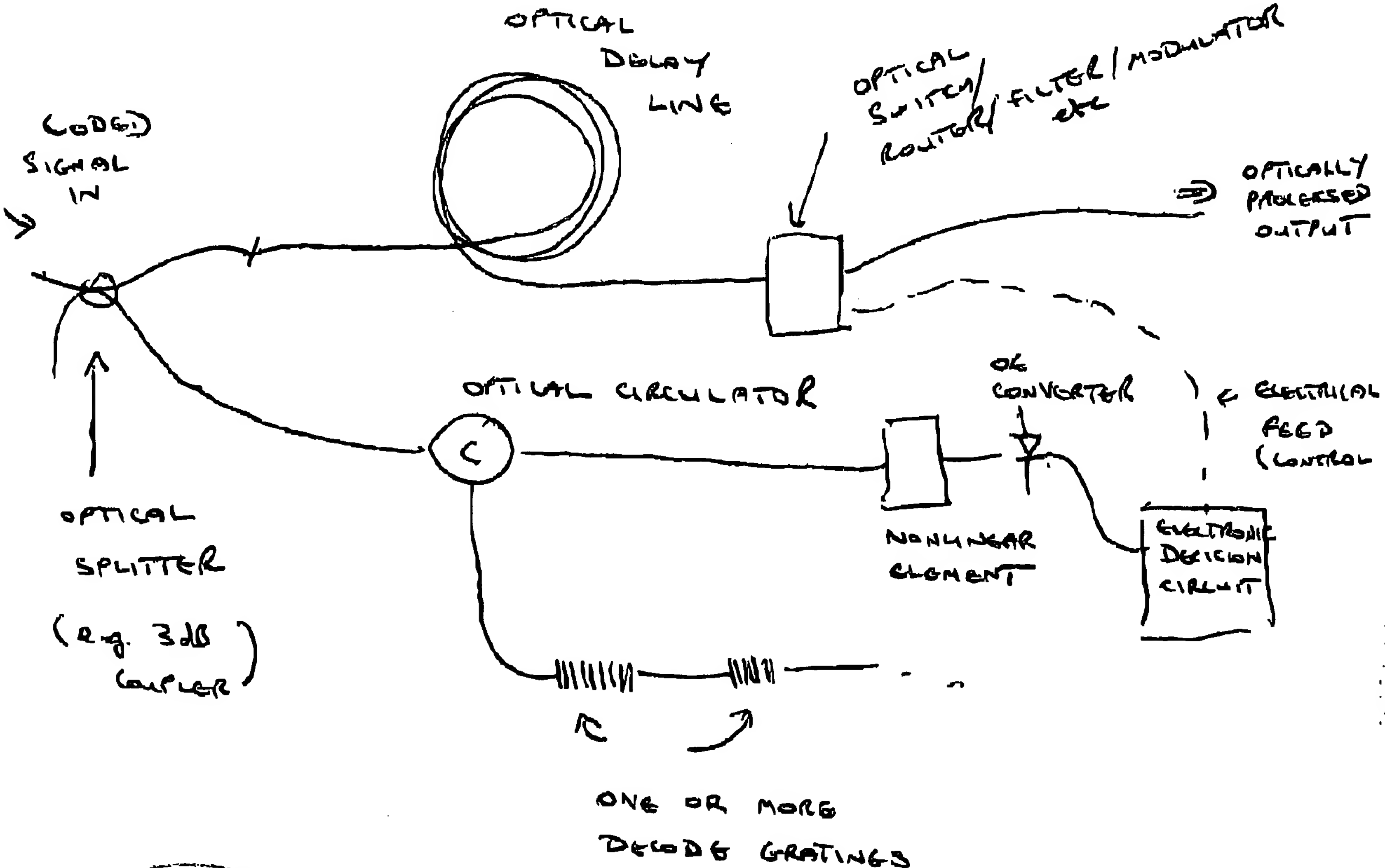


fig A

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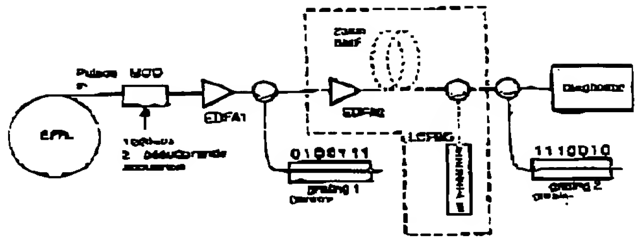

Fig.1 Experimental set-up. The pseudorandom sequence is 2^{31}-1 bits long. LCFBG: Linearly chirped fibre Bragg grating

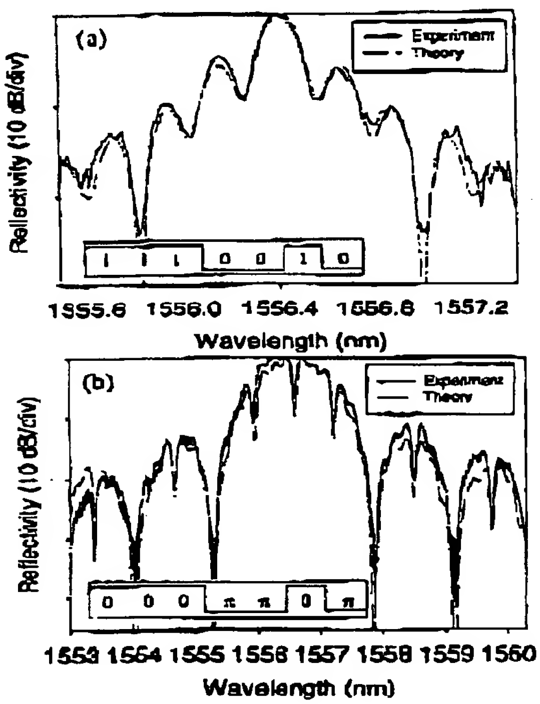

Fig.2 (a) Unipolar grating reflectivity spectrum (theoretical and experimental). The refractive index amplitude superstructure is shown inset. The peak reflectivity of this grating was ~3%. (b) Bipolar grating reflectivity spectrum (theoretical and experimental). The refractive index phase superstructure is shown inset. The peak reflectivity of this grating was ~50%.

(* ENLARGED COPIES OF FIGURES APPENDED)

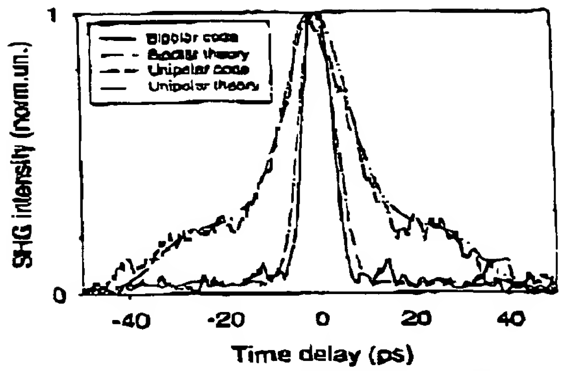

Fig.3 Theoretical and experimental pulse intensity autocorrelation functions for the code:decode process for both the unipolar and bipolar grating pairs.

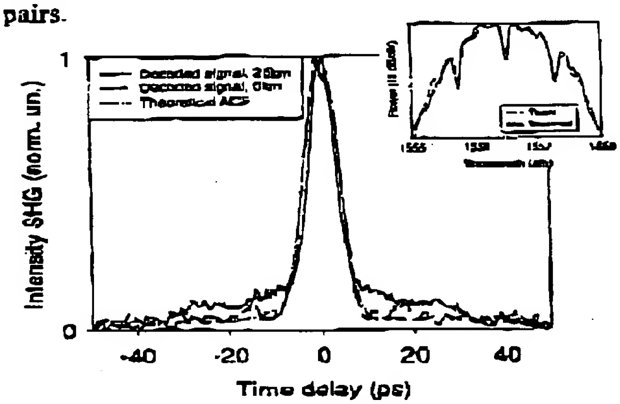

Fig 4 Theoretical and experimental pulse intensity autocorrelation functions for the code:decode process both before and after transmission through 25km of (dispersion compensated) standard fibre.

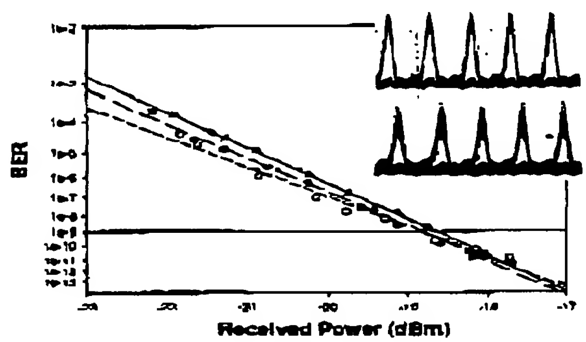

Fig.5 BER curves for back-to-back (open circles), and decoded signal before (closed circles) and after (triangles) transmission: the corresponding eye diagrams are shown inset